6-2003

Ash Fall Historic Park: Field Trip 5

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FIELD TRIP 5

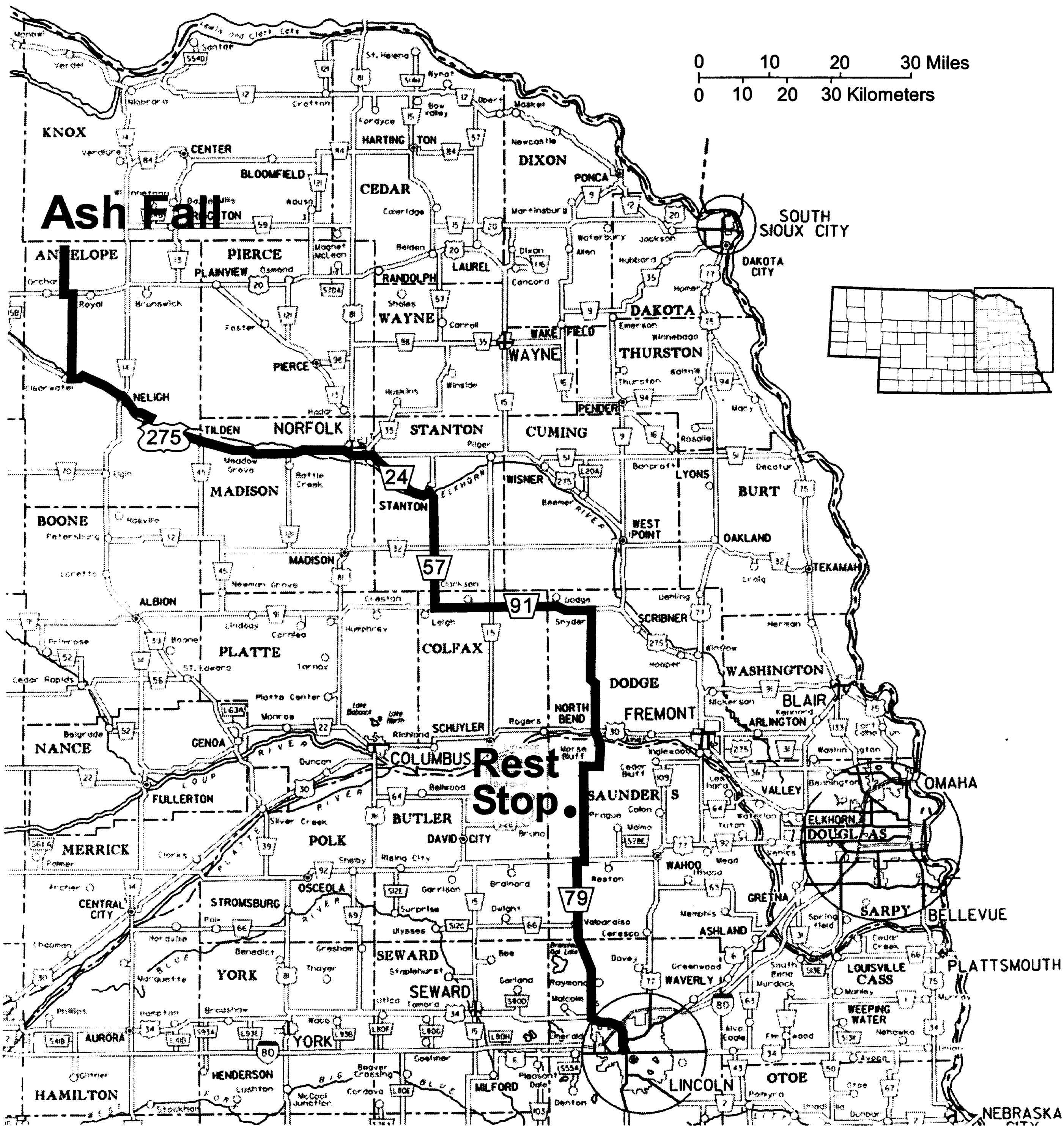
ASH FALL HISTORIC PARK

Bob Diffendal

[Compiled by]

June 19, 2003

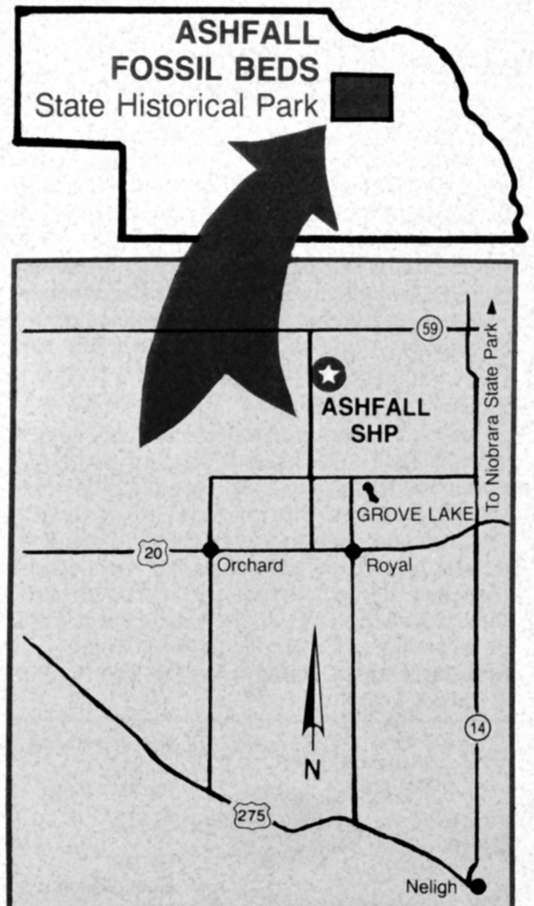
Association of American State Geologists
95th Annual Meeting
Lincoln, Nebraska



Ash Fall
Rest Stop.
0 10 20 30 Miles
0 10 20 30 Kilometers
KNOX
ANTELOPE
PIERCE
CEDAR
DIXON
WAYNE
DAKOTA
THURSTON
STANTON
CUMING
BURT
MADISON
BOONE
PLATTE
COLFAX
DODGE
WASHINGTON
NANCE
MERRICK
POLK
BUTLER
SAUNDERS
DOUGLAS
SARPY
HAMILTON
YORK
SEWARD
CASS
OTOE
NORFOLK
NELIGH
TILDEN
COLUMBUS
FREMONT
SCHUYLER
NORTH BEND
WAHOO
BLAIR
OMAHA
BELLEVUE
PLATTSMOUTH
LINCOLN
NEBRASKA CITY
SOUTH SIOUX CITY
DAKOTA CITY

OPERATING SCHEDULE

Memorial Weekend through Labor Day
9 a.m.-5 p.m. Monday through Saturday
11 a.m.-5 p.m. Sunday
May before Memorial Day Weekend
10 a.m.-4 p.m. Tuesday through Saturday
Closed Sunday and Monday
Labor Day through 2nd Weekend in October
10 a.m.-4 p.m. Tuesday through Saturday
1-4 p.m. Sunday / Closed Monday
By Reservation
School and tour groups may make special arrangements to visit Ashfall between April 1 and Oct. 20 with advance reservations. For details and to make reservations, call the park at 402-893-2000.



ASHFALL FOSSIL BEDS
State Historical Park
P.O. Box 66
Royal, NE 68773
Phone: 402-893-2000

ASHFALL FOSSIL BEDS

A State Historical Park

A Joint Project Of
NEBRASKA GAME AND PARKS COMMISSION
UNIVERSITY OF NEBRASKA STATE MUSEUM

Some 10 million years ago, hundreds of rhinos, three-toed horses, camels and other animals died and were buried by volcanic ash around the edges of a watering hole in what is now northeast Nebraska. Still locked in their death poses, the amazingly well-preserved skeletons of these prehistoric beasts lay undisturbed, wrapped in a blanket of jagged glassy particles, until the 1970s, when scientific study of the fossilized remains began.

Located 6 miles north of U.S. 20 between Royal and Orchard in northern Antelope County, Ashfall Fossil Beds State Historical Park is a joint project of the Nebraska Game and Parks Commission and the University of Nebraska State Museum. The park offers a fascinating and educational experience for the entire family — a chance to step back in time and see what Nebraska wildlife was like long before modern man ventured onto the Great Plains.

Visitors are invited to watch the ongoing excavation of this unique "time capsule." A 2,000 square foot "Rhino Barn" protects part of the deposit, where skeletons are uncovered and displayed exactly where they are found. Walkways give visitors a close-up view as paleontologists carefully brush away the volcanic ash from the massive skulls of native American rhinos and the delicate side hooves of tiny ancestral horses.

The Ashfall site is of national importance and has been featured on the NBC Nightly News, in National Geographic magazine, Ranger Rick magazine and in newspapers worldwide. National Geographic also profiled the area in its book, Giants from the Past.

About Your Visit

Your first stop should be the Visitor Center to see the interpretive displays and the working fossil preparation laboratory. You are invited to ask the paleontologists about their work. Educational programs are presented on regular basis. From the Visitor Center, it is but a short stroll to the Rhino Barn, where new discoveries continue to be unearthed.

Ashfall is situated on 360 acres of rugged rangeland in the scenic Verdigre Creek valley. Nature trails are being developed to help interpret the geology as well as the flora and fauna of the area. Picnicking is permitted on the park, and campers can use nearby Grove Lake Wildlife Management Area near Royal.

Please do not smoke in the buildings or on the trails. Grassland fires are dangerous and spread rapidly. Pets are permitted, but they must be kept on a leash. Collecting fossils or other specimens on the park grounds is strictly prohibited. (If every visitor took a "souvenir," one of Nebraska's natural historic treasures would soon be gone forever.)

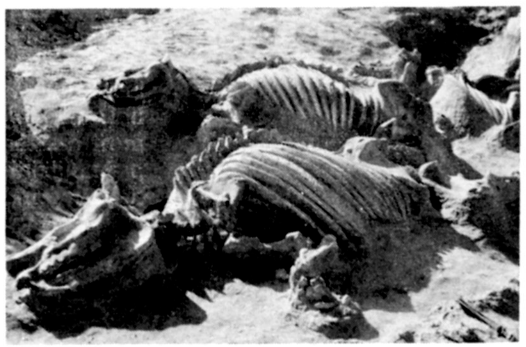
Preservation of Ashfall now and for future generations is made possible by the generosity of the Nebraska Game and Parks Foundation, which purchased the land in 1986, and the Burlington Northern Foundation, which supplied a grant for construction of facilities. Paleontologists and interpretive staff at the site are provided by the University of Nebraska State Museum.

The Ashfall Story

In 1971, heavy spring rains eroded a deep gully at the edge of Melvin Colson's cornfield. Later that year, paleontologist Mike Voorhies happened to find the skull of a complete baby rhino protruding from the side of the gully. It lay near the bottom of a newly-exposed bed of sparkling gray ash and turned out to be the first of more than 100 rhino skeletons excavated by University of Nebraska State Museum crews at what became known as the Ashfall Site.

This wasn't the first time fossils had been found on the Colson farm. Long before the ash bed and its trove of skeletons were exposed to view, scattered bones had been collected from a bed of sandstone which forms a ledge beneath the ash bed. As early as the 1920s, local youngsters found bone fragments on the rocky hillsides. Then, in 1953, Donald Peterson found a partial rhino skull in the sandstone and reported it to the Museum. This important specimen is now on display in the Visitor Center at the park.

The isolated skull found by Mr. Peterson is a good example of the sort of fossils that have made Nebraska's Niobrara River valley famous in the world of paleontology. For more than a hundred years, bone hunters have searched the sandstone walls of the Niobrara and its tributaries for remains of ancient mammals. This area contains North America's most complete record of the 20-million-year history of grassland animals.



A Prairie Pompeii

Even by Niobrara valley standards, preservation of the skeletons in the ash bed is exceptional. Most fossils found elsewhere are incomplete — a jaw here, a leg bone there. That's because natural decay and scavengers tend to break up and scatter skeletons soon after an animal dies.

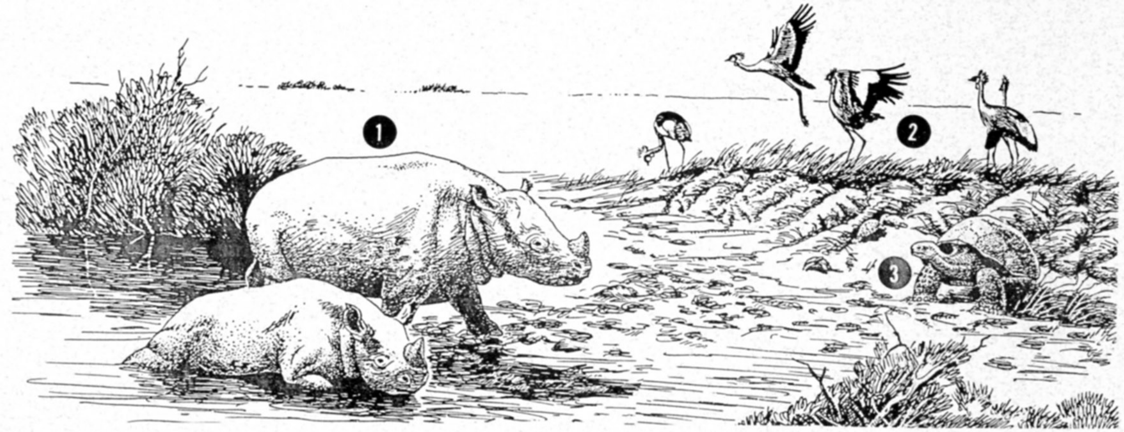
It is extremely rare for whole herds of animals to die and be buried so quickly that their carcasses remain largely intact, as has happened at Ashfall. In the ash bed some rhinos were literally buried in their tracks, with their last footprints clearly visible. Some females have calves next to them, while others have unborn young inside. Many contain the fossilized remains of their last mouthful of grass.

If a time machine were to transport you back 10 million years, you would find a Nebraska covered with sub-tropical grasses and patches of jungle. Discoveries at Ashfall give a detailed picture of what you'd see on such an imaginary safari. Only a fraction of the site has been excavated, so, much remains to be learned. However, it is clear that before the catastrophic ashfall occurred, the area was inhabited by a rich variety of life reminiscent of modern East African savannas. More than 40 species of animals and plants have been identified from fossils collected just below the ash bed.

Disaster Strikes

Sweeping across the plains like a gray blizzard, the sudden fall of volcanic ash must have devastated the landscape. Confused and choking, the animals began to die. Scientists believe that the ash that killed and eventually buried the animals at the park blew eastward from an incredible volcanic eruption in the Rocky Mountains, probably in what is now southwestern Idaho. Part of the great cloud of abrasive dust settled out to a foot or so deep over much of northern Nebraska, then it began to blow around like fresh snow. Eventually the high ground was blown free of ash, but low-lying areas like the marshy pond at the Ashfall site were filled to depths of eight feet or more.

The Victims — 1. Barrel-bodied rhino, 2. Crowned crane, 3. Giant tortoise. In addition to those shown, fossils found in the ash include five species of horses, ranging in size from a sheep to a Shetland pony; three kinds of camels; a hornless, sabertooth deer, and small predators resembling foxes and raccoons.



Like detectives at the scene of a crime, paleontologists are trying to discover exactly what happened at the Ashfall site by studying the arrangement of the bodies of the victims. At the very bottom of the ash bed are small creatures such as pond turtles, birds, musk deer, and small carnivores, which probably died almost immediately. Just above these remains in the ash are skeletons of horses and camels that died next. Many of these early victims were chewed on by scavengers or were crushed and trampled by larger animals that survived longer. Finally, above the horse and camel skeletons are the rhinos. Along with occasional giant tortoises, they were the last to die.

Elusive Predators

As excavation of the site continues, hopes are high that a skeleton of one of the large extinct predators, like a sabertooth cat or bear-dog, will be found. Bite marks on bones already collected and even fossilized droppings full of chewed bone give proof that big meat-eaters were close at hand. Perhaps you will be on hand when a park paleontologist brushes ash from the gleaming saber of a great rhino-killing cat, exposing it to the sunlight for the first time in 10 million years!

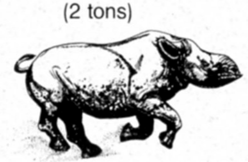
Before The Eruption

Sandstone below the ash bed contains many partial remains of animals that lived and died over a long period of time, perhaps hundreds of years, before the volcanic catastrophe struck. In addition to the species uncovered in the ash bed itself, a number of other animals are found.

Oreodont
(Leaf-eating mammal / 150 pounds)

Bone-Crushing Dog
(150 pounds)

Horned Rodent
(2 pounds)

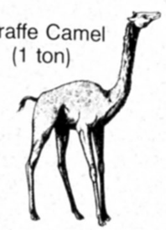


Hornless Rhino
(2 tons)

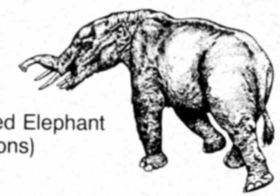
Hedgehog
(8 ounces)

Browsing Horse
(100 pounds)

Three-Horned Deer
(150 pounds)



Giraffe Camel
(1 ton)



Four-Tusked Elephant
(5 tons)

Not Illustrated
- Peccary
- Pocket Mouse
- Gopher
- Bat
- Shrew
- Deer Mouse
- Mole
- Toad
- Frog
- Salamander
- Lizard
- Snakes
- Wolverine-like Predator

A Miocene Rhinoceros Herd Buried in Volcanic Ash

Grant Recipient: Michael R. Voorhies, Division of Vertebrate Paleontology, University of Nebraska State Museum, Lincoln, Nebraska.

Grants 1706, 2059: To excavate the ash bed at Poison Ivy Quarry and to study its fossil contents.

In August 1977, personnel of the University of Nebraska State Museum (UNSM) opened a small test excavation at a promising fossil vertebrate locality in northeastern Nebraska. Several years earlier, while engaged in geological mapping, the writer had discovered a skull of a fossil rhinoceros weathering out of an outcrop of volcanic ash at the site. The skull proved to be articulated with an entire skeleton of a juvenile rhino and to be associated with numerous other complete skeletons. During the short 1977 field season 12 rhinoceros and 3 horse skeletons were collected from an area of only a few tens of square meters. Many other skeletons were noted, but time prevented their being collected.

The deposit is most remarkable. Mass occurrences of fossil mammals are sometimes found (e.g., at Agate Springs, Nebraska; see Matthew, 1923) but in almost all such cases articulated skeletons are rare or absent. The only comparable deposit presently known to the writer is at Höwenegg, Germany, where tuffaceous lacustrine sediments of Miocene age have yielded some 27 skeletons, mostly complete, of horses, antelopes, and rhinoceroses (Tobien and Jörg, 1959). Complete skeletons in volcanic ash have also been reported from Senèze in France (Schaub, 1944) but these are apparently isolated occurrences. The only mass assemblage of articulated skeletons of North American Tertiary mammals known to the writer is that of the Miocene "gazelle-camel" *Stenomylus* (Loomis, 1910) of which at least 40 skeletons, mostly in "death poses," were collected. These camels occur in a sandstone, not a volcanic ash.

Our preliminary work clearly indicated that the new site contained a wealth of information about the Miocene savannah mammalian community of the Great Plains not obtainable at any other known locality. Rapid burial in volcanic ash had apparently preserved details of skeletal anatomy not available in even the most complete Clarendonian rhino and

horse skeletons previously known. The prospect of obtaining an untransported "death assemblage" perhaps representing entire herds of several kinds of hoofed mammals was very exciting. On June 1, 1978, a team from the UNSM began to excavate the site—now known as Poison Ivy Quarry (UNSM Paleontological Locality Ap 116). Four months were spent in the field. Laboratory preparation and analysis of the specimens began in September and is continuing.

Results so far have exceeded the most optimistic expectations. In addition to numerous rhinoceros and horse skeletons (the rhinoceros total is now 70), we also collected excellent specimens of camels and, surprisingly, birds—the latter complete with well-preserved tracheal cartilages and ossified tendons. Another unexpected discovery was exceedingly well-preserved fossil grass seeds inside the rhinoceros skeletons.

The Site

Poison Ivy Quarry lies at the center of the NE1/4, NE1/4, NW1/4, Section 8, Township 28 North, Range 7 West, Antelope County, Nebraska (Figure 1). The fossiliferous exposure is at the head of a ravine draining south into a small unnamed tributary of the south branch of Verdigre Creek. The site is approximately 225 km northeast of Omaha and 50 km south of the confluence of the Niobrara and Missouri Rivers.

West

Topography

Verdigre Creek and its tributaries are dissecting an alluvial plain of low relief in northern Antelope County. Active headward erosion by the tributaries has produced numerous steep-sided ravines in the Verdigre Basin; many contain small bedrock exposures similar to that at the fossil quarry. The site is approximately midway between the northeastern border of the Sand Hills region of central Nebraska and the western border of the glaciated region of eastern Nebraska. About half of the land in the area is used for farming—primarily corn, soybeans, and small grain. The rest, including the quarry site and most other stretches of stream valley, is grazed by cattle.

Geology

The surficial geology of the Verdigre Basin has been discussed elsewhere (Voorhies, 1971, 1973, 1974). The local geologic column exhibits a sequence of flat-lying, predominantly fluvial clastic deposits, ranging from Miocene through Pleistocene in age, which unconformably overlie a Cretaceous marine shale. Approximately halfway through the "stack" of Cenozoic strata is the cap-rock member of the Ash Hollow Formation which contains the fossiliferous ash bed that has been the focus of the

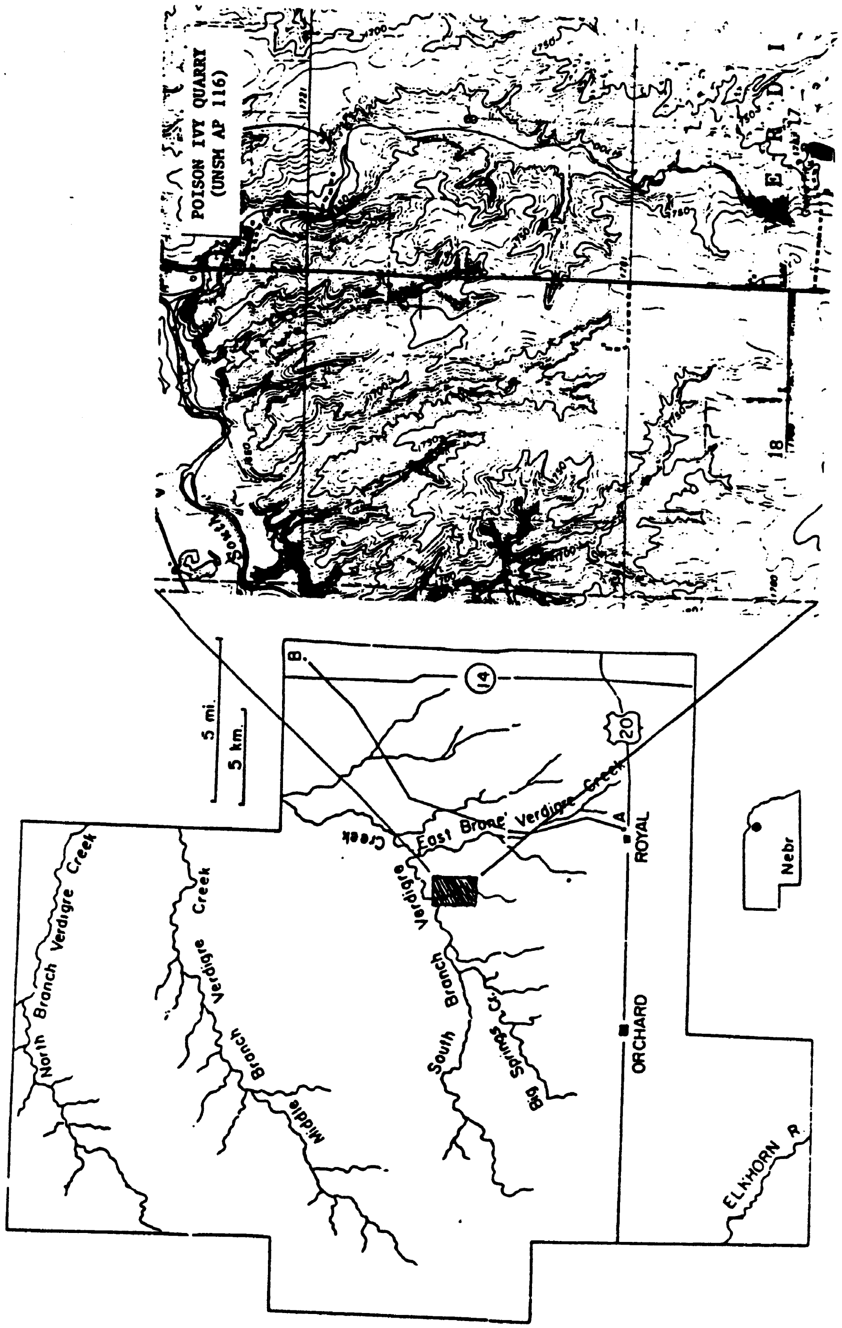


FIGURE 1. Location quarry (detailed map from the Orchard NW Quadrangle, USGS 7½ min. Topographic Series, 1963).

present study. The cap rock is a very widespread sheetlike sandstone deposit, which crops out extensively in the valley of the Niobrara River in northern Nebraska and southern South Dakota. Lenses of cemented sand in the cap rock tend to resist erosion and thus form prominent vertical cliffs and box canyons. This characteristic was noted by Skinner et al. (1968) at its type locality about 160 km west of Poison Ivy Quarry. The cap rock is a rather heterogeneous unit displaying abrupt lateral changes in lithology. Sandstone predominates but lenses of locally derived conglomerate, siltstone, claystone, diatomite, and volcanic ash are common. Volcanic glass, in addition to occurring in discrete beds, some 3 m thick, also occurs as disseminated shards among the sand- and silt-sized clasts in the bulk of the unit. Fossil vertebrates have been collected by the writer from several dozen exposures in the Verdigre Basin. The fossils are most commonly found in sandstone and tend to be broken and abraded.

The stratigraphy in the immediate vicinity of Ap 116 is shown in Figure 2. Note that the fossiliferous ash bed is more than 2.5 m thick at the fossil quarry but that it thins rapidly toward the north and west. The ash lies about a meter above the base of the cap-rock member. At the quarry it rests directly on a hard, calcareous-cemented sandstone containing rounded fragments of fossil bones and teeth. The lower contact is very sharp and well defined. The ash itself is unconsolidated except in the top few centimeters, which grade into a slightly consolidated silty clay. In addition, a layer of detrital sand and silt mixed with ash which occurs a few centimeters above the base of the ash bed is slightly consolidated. Except for the latter unit, the ash is remarkably pure and free of detrital material. The ash is laminated throughout its thickness except in the bottom few centimeters and (sometimes) adjacent to fossil skeletons where stratification tends to be obscure or absent. In plain view, many of the bedding planes in the ash show symmetrical ripple marks. In the immediate vicinity of the quarry the ash bed fills a depression that deepens toward the north and east. The top of the ash, in contrast with its base, is horizontal.

The overall geometry of the ash bed, its well-preserved continuous, horizontal stratification and the presence of ripple marks all suggest that the ash accumulated in a body of standing water—a pond or lake. (The size of the presumed body of water cannot yet be determined as only part of the southwest "shoreline" is exposed for study.) Deposition of the ash bed appears to have been essentially continuous and very rapid. The only lithologic evidence of significant interruption of sedimentation detected so far is the "clastic wedge" of silty sand mixed with ash which occurs near the base of the ash bed. This unit appears to represent clastic material washed into the pond or depression from the pre–ash-fall land surface shortly after the initial ash fall. Paleontological evidence discussed below suggests that the washing in of locally derived debris along

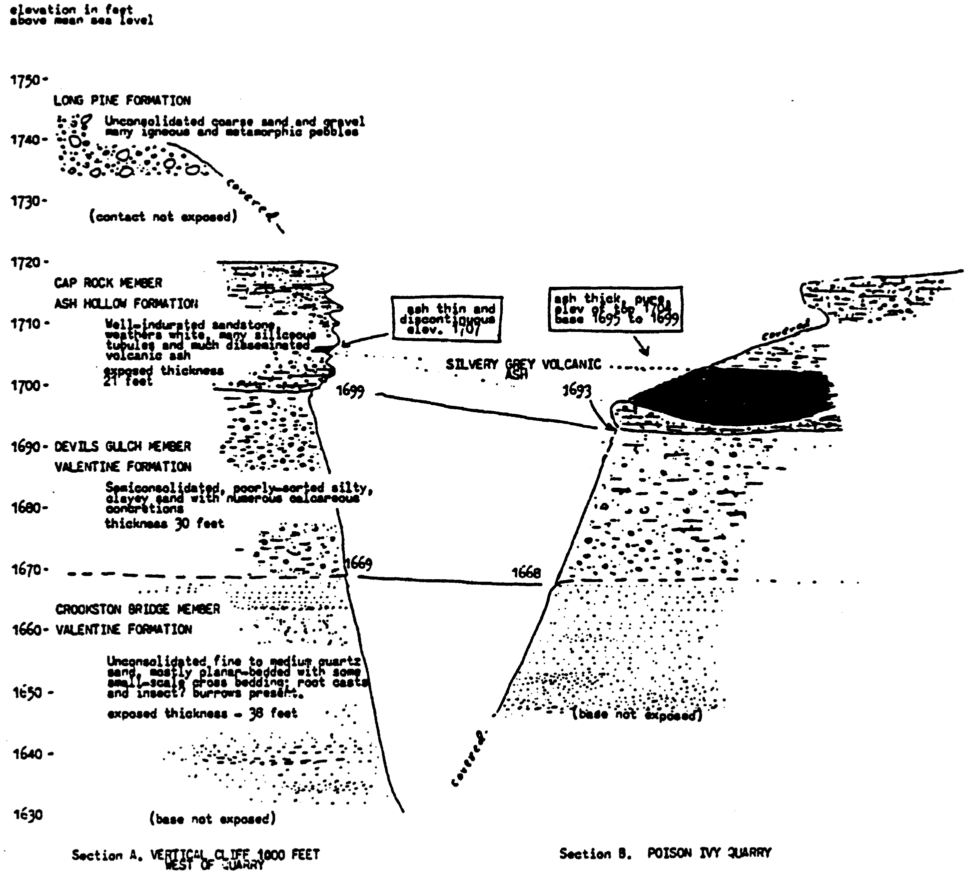


FIGURE 2. Geologic sections in the vicinity of Poison Ivy Quarry.

with ash from the initial fall probably represents a hiatus of no more than a few weeks. After this interruption, the depression appears to have filled to the brim very rapidly; no further non-ash contaminants reached the depression.

THE 1978 EXCAVATIONS

Test excavations in 1977 indicated that a concentration of skeletons probably lay buried beneath a grass-covered hillside between two ravines about 30 m apart. The fossiliferous horizon lay just under the sod at the

downslope (southwestern) edge of the target area, but was covered by as much as 5 m of apparently unfossiliferous overburden at the upslope (northeastern) margin. Because of the great volume of overburden, and the considerable hardness of some of it, we decided to have it removed by bulldozer. At the beginning of the field season, in early June, further test pits were hand-dug to verify the previous conclusion that skeletons were present only at the base of the ash bed. Finding no evidence to the contrary, we arranged for a bulldozer to clear away the overburden to approximately 0.7 m above the level of the highest known bone in the ash bed. Members of the excavation team watched for fossils as the bulldozing proceeded; but none was observed except a fragment of tortoise carapace, which occurred about a meter above the bulldozed floor. It was not clear whether the tortoise had originally been buried high in the ash bed or had been brought to that level by the burrowing activity of a modern animal. The latter is judged more probable. Definite rodent burrows are common, especially at the southeastern edge of the excavation.

Within three hours the bulldozer had prepared a level surface roughly 30 × 15 m. This area was surveyed and laid off into a grid of 3-m squares (Figure 3). Vertical control was established with a pin surveyed into the northeastern wall of the excavation. Several squares were excavated simultaneously; unexcavated walls were left between squares as a record of the stratigraphy. Paleontological, lithologic, and bulk sediment samples were located by grid square number (assigned at the northwestern corner). Position within a square and stratigraphic position were plotted and sketched on planimetric maps of the excavation. Major features were photographed. Approximately half of the bulldozed area, or 30 squares, was excavated in 1978.

Most of the vertebrate fossils were collected by conventional plaster-jacketing techniques after having first been treated with a polyvinyl acetate preservative. Usually, only enough matrix was removed from each specimen to determine its identity, limits, and orientation before applying the cast. We did, however, expose several skeletons rather completely so that informative photographs could be taken. In most cases, we found that less damage to the specimens resulted when field cleaning was kept to a minimum.

The fact that most of the specimens were partly or entirely articulated created special problems in collection. An adult rhinoceros skeleton enclosed in plaster would weigh at least a ton and would be very difficult to handle. Therefore, we generally removed the skeletons in smaller, more manageable sections. Each hind limb (femur to foot) of an adult rhino, for example, was usually collected as a unit. The pelvis, sacrum, and caudals usually came out together. Ribs were usually removed individually but in some cases bundles of ribs or entire rib cages were collected as units. It

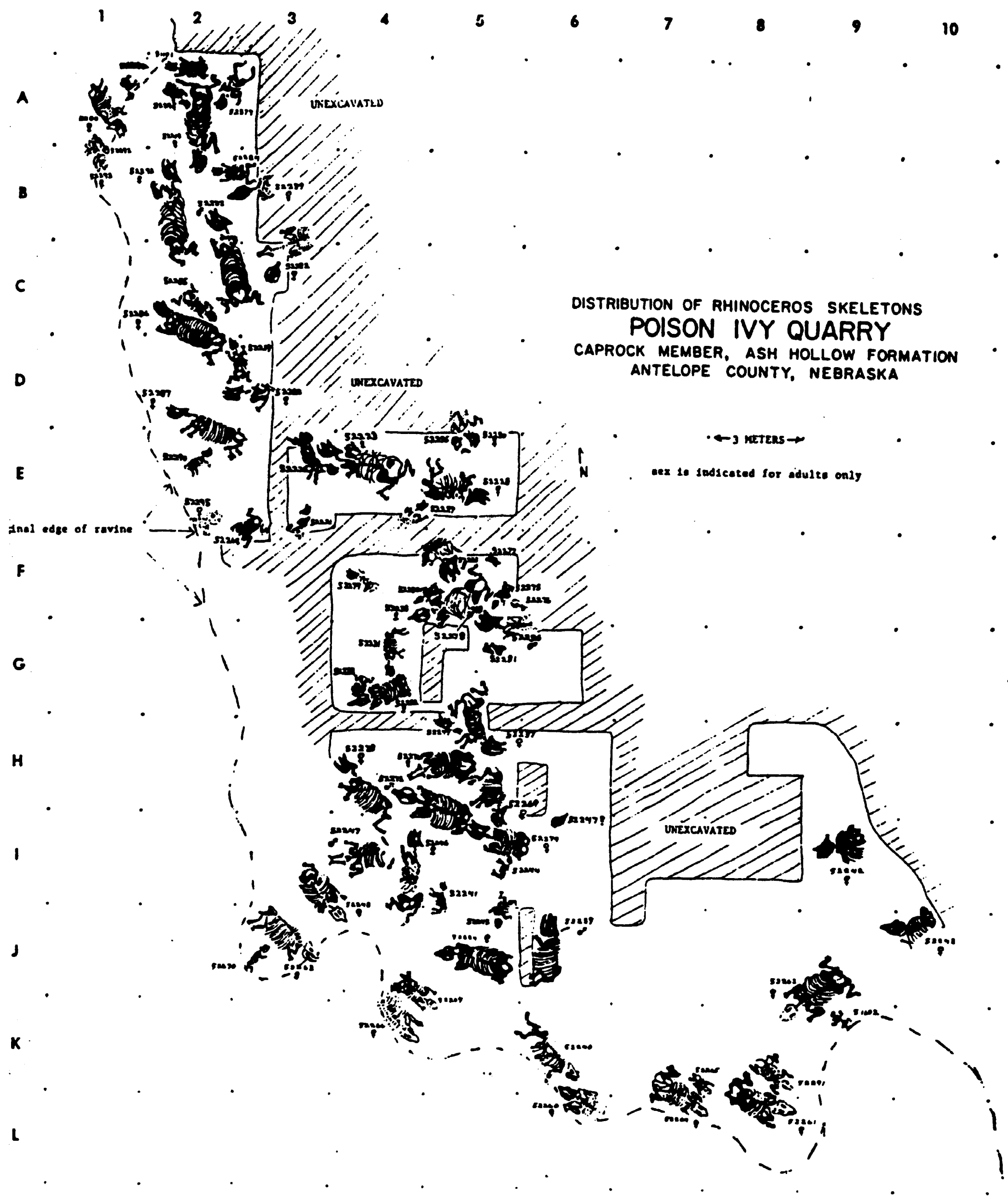


FIGURE 3. Distribution of rhinoceros skeletons in Poison Ivy Quarry, Cap Rock Member, Ash Hollow Formation, Antelope County, Nebraska. Sex is indicated for adults only.

was often possible to collect entire skeletons of smaller animals (horses, juvenile rhinos) in one or two casts.

Skeletons were often intertwined and overlapped making excavation exceedingly tedious and slow. It was not always clear, in the field, which limbs belonged with which skulls. Fortunately, our field records are sufficiently clear to match bones of individual skeletons once the specimens have been prepared in the laboratory.

Laboratory preparation of the fossils has been very time-consuming but rewarding. Many of the specimens are preserved in exquisite detail. The bones are only slightly mineralized, however, and frequently still have spaces unfilled by sediment. They are consequently exceedingly fragile, which considerably increases the time needed for preparation. Our laboratory procedure has been to open the field jackets and prepare one side as completely as possible without disturbing the original arrangement of the bones. This maximizes our ability to reconstruct accurately the preburial postures of the skeletons, which in turn offers one of the most important clues to the origin of the deposit. Before fossils are removed from their field jackets and completely cleaned, sketches and/or photographs are made to document their original orientations.

During the 1978 field season, an estimated 18 tons of field-packaged vertebrate fossils were shipped from Poison Ivy Quarry to the University of Nebraska State Museum for preparation and study. This material consisted of 1508 individually numbered items whose original horizontal and vertical position in the quarry can be determined by reference to the field records.

When microvertebrate remains were observed during excavation, bulk sediment samples were collected for screen washing. Our success in obtaining small vertebrates was very disappointing. Although we screened several tons of sediment, only a few incomplete microvertebrates were found.

As the fossils are prepared, they receive the number of the field jacket that contained them. This "field number" remains with the specimen as a guide to its provenience within the quarry. Ultimately, each bone also receives a "permanent" UNSM number. In cases where there is little or no doubt about the association of elements of an individual skeleton, a single UNSM number is applied to all bones of that individual. Isolated bones of unknown or doubtful affinity each receive a separate UNSM number.

By the end of February 1979, about 300 field casts, approximately a fifth of the 1978 collection, have been opened and at least partly prepared. Included are all of the rhinoceros skulls and jaws, about two-thirds of the horse and camel skulls and jaws, and a sampling of the birds, turtles, and smaller mammals.

Composition and Age of the Fauna

Although rhinoceros skeletons make up the great bulk of the materials collected from the ash bed, the 1978 excavations uncovered a considerable variety of smaller animals as well. Currently identified vertebrates from Poison Ivy Quarry are listed in Table 1. Detailed identification of the nonmammalian remains has not yet been attempted. It is clear, however, that at least two kinds of turtles are present: a large land tortoise and a small aquatic turtle. Likewise at least two kinds of birds are represented: a long-legged (wading?) bird and a raptorial bird the size of a hawk.

The mammals belong to species already recognized in late Clarendonian faunas in the northern plains: for example, the Minnechaduza (Webb, 1969) of Nebraska and the Mission (Macdonald, 1960) and Big Spring Canyon (Gregory, 1942) local faunas in South Dakota. The horses *Pseudhipparion gratum*, *Cormohipparion occidentale*, and *Pliohippus supremus*, the rhinoceros *Teleoceras major*, the camel *Procamelus grandis*, and the oreodont *Ustatochoerus* cf. *skineri* occur jointly in all of these faunas (sometimes under other names) and their presence together in the ash bed strongly indicates a close correlation with these sites. The horse, oreodont, and rhino species are distinctly more advanced than their counterparts in the early Clarendonian Burge fauna (Webb, 1969). A late Clarendonian age for the Poison Ivy Quarry assemblage is thus assigned with considerable confidence.

Table 1. Inventory of Fossil Vertebrates Collected from Poison Ivy Quarry (University of Nebraska State Museum Locality Ap 116) by the End of the 1978 Field Season

Kinds of Animals	Minimum Number of Individuals
Rhinoceroses (*Teleoceras major*)	70
Horses (in order of abundance: *Pseudhipparion gratum*, *Cormohipparion occidentale*, *Pliohippus supremus*, *Calippus* sp., cf. *Astrohippus*)	>20
Camels (*Procamelus grandis*, *Aepycamelus* sp.)	6
Small "deer" (cf. *Longirostromeryx*)	5
Carnivores (cf. *Cynarctus*, cf. *Leptocyon*)	2
Rodents (heteromyid indet.)	1
Birds	>10
Turtles	>10

Rhinos

The short limbs, nasal horns, large premaxillary bone and upper incisors, and hypsodont cheek teeth leave no doubt that the rhinoceros remains from Poison Ivy Quarry represent the genus *Teleoceras* Hatcher. A single, quite variable species appears to be represented by all the material studied so far (70 individuals, mostly skulls and teeth). Most previous authors have referred the characteristic late Clarendonian medium-sized *Teleoceras* to Cope's species *T. fossiger*. Skinner et al. (1968) however, have shown that the type specimen of *T. major* Hatcher, the genotypic species, was collected from rocks equivalent in age to the Cap Rock Member of the Ash Hollow Formation and is specifically distinct from the later, larger species *T. fossiger*, characteristic of Hemphillian age sediments. Tanner (1975) has also referred Cap Rock teleocerine material to *T. major* and has figured a maxilla from a prolific Cap Rock site, the Quinn Rhino Quarry (UNSM Bw-101) as evidence that *T. major* has smaller, simpler cheek teeth than *T. fossiger* from stratigraphically higher sites. On the basis of skulls collected in 1977 from Poison Ivy Quarry, Voorhies and Stover (1978) found that the type of *T. major* falls within the size and morphological range of the ash-bed rhino and concluded that the latter can be referred with confidence to *T. major*.

Horses

Five of the eight known genera of Clarendonian horses occur in Poison Ivy Quarry. All five are grazers, subfamily Equinae; neither *Hypohippus* nor *Megahippus*, the Clarendonian browsing horses, subfamily Anchitheriinae, has yet been encountered in the ash bed. The three most abundant horses, each represented by skulls, jaws, and skeletons of adults and juveniles, are *Pseudhipparion gratum*, *Cormohipparion occidentale*, and *Pliohippus supremus*. In the material so far prepared, *Calippus* is represented only by a skull and mandible and *Astrohippus* by a skull. When fully prepared these specimens will allow a detailed anatomical comparison to be made among these horses in an effort to understand how so many closely related animals could occupy the same area at the same time without competitively excluding each other.

Camels

The commonest camelid at Ap 116 is *Procamelus grandis*; five individuals, four of them less than a year old, have been identified so far. The limbs of a giant camel, probably *Aepycamelus* were collected in 1978; the remainder of the skeleton appears to be present and will be collected in 1979.

Other Mammals

Several badly trampled skeletons of the small cervoid *Longirostromeryx* were collected and constitute the first definitely associated postcranial material of this animal. Jaws and associated postcranials of the omnivorous canid *Cynarctus* and teeth of the fox-sized canid *Leptocyon* are the only record of carnivores in the fauna except for several large coprolites and the presence of bite impressions on a few of the horse bones. A single tooth of a pocket mouse comparable to *Perognathus* is the only record of a rodent in the fauna.

Origin of the Deposit

I interpret the sequence of events leading to the death and burial of the animals at Poison Ivy Quarry as follows:

- The site was originally a shallow depression, possibly a pond formed as an oxbow, on the floodplain of a low-gradient stream.

Evidence: The ash bed is lenticular in shape; its thin, continuous laminations and ripple-marked bedding planes indicate accumulation in standing water with little or no current action. The sandstone beneath the ash bed in contrast is poorly sorted and laterally discontinuous with numerous fossil root casts and some cross bedding.

- The site was a water hole for local populations of large mammals.

Evidence: Numerous fragmentary bones and teeth (mostly rhinos, horses, camels, mastodonts, and turtles) occur in the silty sand just below the ash bed. These remains are broken, abraded, and scattered, possibly by trampling. Fish remains at this level indicate the presence of permanent water.

- A volcanic ash fall buried the local landscape—probably to a depth of 0.1 to 0.2 m.

Evidence: This is the thickness of the lowermost portion of the ash bed at Poison Ivy Quarry; it is uncontaminated with sand and silt and therefore almost certainly represents direct air-fall ash. Volcanic ash varying in thickness from a few centimeters up to 4 m crops out discontinuously at the same stratigraphic level (a few meters above the base of the cap rock) over an area of several hundred square kilometers in the Verdigre Valley in the vicinity of the quarry.

- Herds of three-toed horses, camels, and small deer died catastrophically during the late phases of the initial ash fall (large numbers of pond turtles and wading birds perished at the same time).

Evidence: Skeletons of these animals occur *above* the basal ash considered to be original air-fall material. Evidence of simultaneous death is twofold: study of individual age at death of the animals and intermingling of the skeletons at the same stratigraphic level (sandy ash) in similar states of preservation.

- Some carcasses decomposed slightly and were subjected to scattering; trampling, scavenging, and water currents probably all played a part in this.

Evidence: The skeletons of the smaller animals are somewhat disarticulated and scattered through the layer of sandy ash that occurs above the pure, basal ash and represents an influx of locally derived material into the pond. The sandy ash contains some small-scale cross bedding indicating weak currents. A rainstorm triggered by the ash fall may have supplied the necessary water. At least one horse skull shows two punctures almost certainly caused by the canine teeth of a scavenger. Many of the skeletons exhibit differential smashing (some parts well preserved, adjacent portions flattened and broken) in a manner highly suggestive of trampling by animals.

- Herds of rhinos and a few late-coming horses and camels arrived at the water hole and died, again very rapidly, perhaps a week or so after the principal die-off of smaller animals.

Evidence: The rhinoceros skeletons almost all are lying on, not in, the sandy ash—in contrast with the horses, camels, and birds; they frequently directly overlie smaller skeletons and are better articulated and less scattered than the smaller skeletons. Rapid death of the rhinos is indicated by the studies of individual age reported below.

- The rhino skeletons were rapidly buried by ash, probably in a few weeks or less.

Evidence: The three-dimensional preservation of most of the rhinoceros skeletons, many of them in crouched positions with the legs directly beneath the body, indicates that the carcasses were still largely intact when buried.

- The depression completely filled with ash, sealing in the skeletons. This was probably accomplished within a few weeks or less by wind blowing in ash from the surrouding ash-blanketed countryside.

Evidence: Rapid infilling is indicated by the lack of major hiatuses in the laminated ash above the level of the skeletons. Wind rather than water transport is suggested by the lack of sand and silt in the upper portions of the ash. Any significant erosion by water would surely have cut through the thin loose mantle of ash on the hillsides and washed sandy debris into the pond. This did not happen, suggesting that filling was complete before the next major rainstorm.

In summary, I suggest that the fossils represent populations of animals that died catastrophically around a shallow water hole during or shortly after a major ash fall that blanketed the surrounding countryside with volcanic ash. Smaller animals (horses, camels, birds) died first and began to decompose, but were buried in a mixture of sand and ash washed into the water hole, possibly during a rainstorm. Before disarticulation of the smaller animals was well advanced, but after deposition of the sandy ash, a large number of rhinoceroses entered the water hole, trampling many of the smaller skeletons; the rhinoceroses then died and were quickly covered by volcanic ash, which probably sifted into the water hole as the ash blanket on the landscape was reworked by wind.

Did *Teleoceras* Form Herds?

The mere presence of a large number of individuals at one location does not prove gregariousness in fossil (or living) animals. For example, otherwise solitary animals might congregate around a shrinking water hole in times of drought and might die and be buried together; such an aggregation could then be mistakenly taken as evidence for herd-forming behavior. Likewise if a few animals died and were fossilized at the same place each year over a long period of years, the large fossil "population" that accumulated could be misinterpreted as a herd.

Keeping such caveats in mind, I believe that the Poison Ivy rhinos represent a herd, a genuine social group. The evidence suggesting this derives from several sources. The stratigraphy of the site and condition of the skeletons clearly indicate that the animals died together, very rapidly; the carcasses did not accumulate over a period of many years. Secondly, as discussed more extensively below, the biological composition of the fossil rhino "population" has several features, especially a highly unbalanced adult sex ratio, which are difficult to account for on the assumption that the quarry sample represents a random sample of nongregarious animals from a large area. If *Teleoceras* individuals lived solitary lives, as do modern rhinos, and normally were widely dispersed then their congregation, death around a water hole should result in a sample consisting of roughly half males and half females. As shown below, this is not the case; the fossil rhino population is structurally more similar to that of modern gregarious hoofed animals than to that of solitary forms.

Population Dynamics

The geological/taphonomic evidence discussed above suggests that the skeletons in the ash bed provide us with a "snapshot" of living herds as they existed at a remote moment in time. The mechanisms of death and burial appear to have been sufficiently nonselective that the ratios of young to old and male to female animals were preserved intact, without the usual distorting factors (e.g., sorting, abrasion). The sample from Ap 116 is, therefore, almost ideal for study using the techniques of population dynamics (Deevey, 1947).

Few studies of this type have been attempted with fossils. Kurtén (1953) pioneered the approach; more recently Voorhies (1969) and Saunders (1978) have analyzed fossil "populations" and tried to extract meaningful information about birth, death, and reproductive rates from them. In almost all studies of population dynamics in extinct animals it has been necessary to estimate the proportion of very young individuals. Probably because of their susceptibility to destruction (e.g., by weathering, scavenging), remains of juveniles tend to be underrepresented in fossil collections. In contrast, the Poison Ivy Quarry sample studied so far contains a large number of juveniles. Young rhinos, horses, and camels appear to be present in the high numbers expected in healthy herds. Only the rhino sample has been studied in any detail, however. Preliminary results are given below.

Age and Sex Distribution

The age at death of each of the 70 individual rhinoceroses collected so far has been determined on the basis of tooth eruption and wear (Kurtén, 1953; Voorhies, 1969). Table 2 shows the age distribution of this sample.

The skulls of the youngest animals—those retaining the full deciduous (milk) dentition—fall readily into three distinct age groups with no intermediates. These are interpreted as three successive year-classes of calves. The tight clustering of the rhino calves into age groups allows three important inferences to be drawn:

- Births were seasonal in *Teleoceras* as in modern hoofed mammals of the Great Plains (bison, prongbucks) rather than occurring at all seasons as in modern African rhinos (Goddard, 1966).
- The animals must have died over a very short period of time—surely less than a month—otherwise much more "blurring" of the age groupings would be expected.
- The deaths must have occurred shortly before the calving season (spring?) because members of the youngest age group already have considerable wear on their teeth. (Additional support to this interpretation is provided by the presence of probable near-term fetuses in the pelvic cavities of several adult females.)

The adult rhinos cannot yet be assigned accurate ages in years although when a somewhat larger sample becomes available (perhaps 150 or so) this may be possible. If the crown heights of adult teeth are measured and the values plotted, distinct, more-or-less evenly spaced clus-

TABLE 2. Age Distribution of Fossil Rhinoceroses *(Teleoceras major)* from Poison Ivy Quarry

	NUMBER OF INDIVIDUALS	INFERRED AGE IN YEARS
Group I (young calves)	14	¾
Group II (middle calves)	10	1¾
Group III (old calves)	8	2¾
Group IV (subadults)	5	3¾-6
Group V (young adults)	21	6-11
Group VI (middle-aged adults)	11	11-20
Group VII (old adults)	none	20-40

Age assigned to groups on basis of tooth eruption and wear.

ters can be interpreted as year classes. In the writer's experience, a sample size roughly equal to three or four times the maximum longevity (in years) of a hypsodont ungulate is necessary to ensure the success of this method. A second method of precise age determination—the interpretation of growth lines in the cementum or dentine in teeth—is now being attempted on a small scale in our laboratory and shows some promise of success. The method has the disadvantage of involving some unavoidable destruction of specimens in the extraction and sectioning of teeth.

Possibly a combination of techniques—a primary age grouping based on tooth wear with supplementary detailed growth ring studies of selected individuals spanning the age spectrum from juveniles through older adults—will provide us with an accurate picture of the age distribution within the *Teleoceras major* sample at Poison Ivy Quarry.

SEX DIFFERENTIATION

Skulls of adult rhinos from Ap 116 show marked sexual dimorphism. As long ago as 1898, H. F. Osborn studied a number of skulls and jaws of *Teleoceras fossiger* from various localities in Kansas and Nebraska and stated that individuals with large lower tusks were males while small-tusked individuals were females.

This evidence was strongly suggestive but not wholly convincing because it was based on specimens from over a large area, not demonstrably the same age. Osborn's hypothesis, however, is strikingly confirmed by our discovery of fetal bones within the pelvic cavity of an adult skeleton (UNSM 52373) with small tusks (20.1 × 22.5 mm in cross section). The difference in tusk width between males and females was very significant. Other possibly sex-related features such as overall size and horn size appear to differ much less than do tusk diameters.

SEX DISTRIBUTION

Using tusk size as a criterion for sexing the adult rhinos, we arrive at a rather surprising sex distribution: Only 5 adult males are present compared with 32 females. The unbalanced sex ratio is particularly evident in the young adults among which females outnumber males 25 to 1.

In view of the large sample size, the scarcity of males is unlikely to be due to chance. Likewise it seems unlikely that males somehow preferentially escaped death—the high percentage of "prime" adults in the death assemblage strongly argues that the agent of mortality was nonselective: All animals present, regardless of "vigor," were killed.

My present interpretation, then, is that adult males, especially young ones, were greatly outnumbered at the water hole (at least the part excavated so far) at the time the ash accumulation occurred. This suggests that the social behavior of *Teleoceras* was much different from that of modern African rhinoceroses, which are generally solitary except for mother-young associations and brief encounters during breeding (Leuthold, 1977). A social grouping more like that in some modern gregarious ungulates is suggested. For example, plains and mountain zebras (Leuthold, 1977) form stable breeding herds of females accompanied by single adult stallions. Young subdominant males are actively excluded by the "harem master" and form "bachelor herds" of their own. (Several skeletons exhibit healed broken ribs suggesting that active butting contests occurred.)

GRASS SEEDS AS CLUE TO DIET

Tiny silicified plant fossils were first noticed when the hyoid apparatus—tongue bones—of an adult female rhinoceros was being cleaned. In view of the possibility that these might represent food residues, we began to examine the matrix removed from the fossil mammal skeletons even more carefully to determine whether plant fragments were undigested food or had been introduced into the skeletons along with the ash particles. After carefully subjecting cubic meters of ash outside the skeletons to fine screening and flotation without finding any "seeds," we are now confident that the rather numerous plant fossils found inside several of the skeletons represent food ingested by the animals shortly before death.

The seeds (technically floral bracts) have been identified by Joseph R. Thomasson, an authority on fossil grasses, as belonging to three extinct species: *Berriochloa primaeva*, *B. nova*, and *B. communis*. The specimens are amazingly well preserved with details of the epidermal cell patterns readily observable in scanning electron photomicrographs. The new evidence conclusively shows that this animal was a grazer.

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MICHAEL R. VOORHIES

Geologic Framework of the Niobrara River Drainage Basin and Adjacent Areas in South Dakota Generally East of the 100th Meridian West Longitude and West of the Missouri River

R.F. Diffendal, Jr.
and
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Nebraska Geological Survey
Report of Investigations No. 9

Conservation and Survey Division
Institute of Agriculture and Natural Resources
University of Nebraska-Lincoln

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Geologic Framework of the Niobrara River Drainage Basin and Adjacent Areas in South Dakota Generally East of the 100th Meridian West Longitude and West of the Missouri River

by R.F. Diffendal, Jr.[1]
and
M.R. Voorhies[2]

Abstract

General geology and stratigraphy of the Niobrara River drainage basin in Nebraska and adjacent parts of South Dakota generally west of the Missouri River is reviewed. Of particular importance are the correlation of the Long Pine Formation of Pliocene age in Nebraska with the Herrick Gravels in South Dakota, the recognition of the members of the Ogallala Group named by Skinnner, Skinner and Gooris (1968) and by Skinner and Johnson (1984) in the basin, the acceptance of the relationships of the Miocene and older Tertiary units in the basin to those in the part of the study area in South Dakota as proposed by Skinner and Taylor (1967), Skinner, Skinner and Gooris (1968) and by Skinner and Johnson (1984), and the recognition of the Rosebud Formation of the Arikaree Group (Skinner, Skinner, and Gooris, 1968) in the basin. Rocks now included in the Rosebud were placed previously in the White River Group by the Conservation and Survey Division (Burchett, 1986). A refined geologic map of the area shows the currently known distributions of all of the major units, including the Long Pine/Herrick, the Rosebud, and the Chadron formations, none of which has been shown on a map of the study area previously.

Introduction

This report covers the geology of the eastern part of the Niobrara Basin in Nebraska and adjacent parts of South Dakota. This geology includes the present scene and the geologic history of the basin. Readers who are interested in the geology of the western part of the basin (not included in this report) should read the works of Swinehart and Diffendal (1990), Swinehart and others (1985), and Souders (1981) cited in the references, the works of R. M. Hunt, Jr., of the University of Nebraska State Museum and his students (Hunt, 1978, 1990; Hunt and others, 1983; Yatkola, 1978), and the work of Skinner, Skinner, and Gooris (1977) in the library of the University of Nebraska-Lincoln. These reports contain references to most of the earlier geologic work done in that area.

The geology of the area has been studied for a long time. As early as 1845, Charles Lyell, the famous English geologist, published a geologic map of the United States that showed the presence of Cretaceous strata in the area about the mouth of the Niobrara River and the adjacent Missouri River valley (Diffendal, 1993). The Warren, Meek, and Hayden surveys in the late 1850s resulted in considerable expansion of knowledge of the geology of the Great Plains, including the Niobrara Basin. In the late 1800s and the early 1900s, the focus of work in the basin was mainly paleontological. The history of these activities is reviewed in detail by Voorhies (1990b, 1990c). Considerable debate arose in the 1930s about the stratigraphic names of some of the strata in the basin (Johnson, 1936, 1938; Lugn, 1938, 1939) and was resolved then for a time (Condra and Reed, 1959).

Our present understanding of the general geology of the Niobrara drainage basin east of the 100th meridian comes from the works of a limited number of geologists who have studied the area and written reports about it

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mostly since 1950. We present one figure and two tables that show our view of the current state of geological knowledge in the area. Many of the formation and member names applied to Cenozoic strata in the area were defined by Morris Skinner and his co-workers at the American Museum of Natural History in New York (table 1). M. R. Voorhies of the NU State Museum has also published on the geology and paleontology of the Cenozoic units in the basin (Voorhies, 1969, 1971, 1973, 1974, 1981, 1985, 1987a, 1987b, 1990a, 1990b, 1990c, and Voorhies and Goodwin, 1989). Other paleontological studies were done by Backlund and others (1991), Cobban (1951), Cobban and Scott (1964), Dietrich (1951), Evander (1978), Haffner and others (1990), Johnson and Milburn (1984), Landon (1985), Loetterle (1937), and Wellstead (1981). Groundwater studies that included considerable information on the geology of parts of the lower basin were done by members of the U.S. Geological Survey and members of the Conservation and Survey Division of the University of Nebraska-Lincoln: Condra (1903), Cronin and Newport (1956), Gosselin (1991), Newport (1959), Reed (1944), Souders (1976), and Souders and Shaffer (1969). Schulte (1952) and Mendenhall (1953) did theses on the geology of two counties and part of a third in the basin.

Damsite investigations were done by L. D. Cast and other workers at the U.S. Bureau of Reclamation and by workers in other agencies and organizations (Cast, 1988; Niobrara River Basin Development Association, 1951; U.S. Bureau of Reclamation, 1952, 1962, 1977, 1978, 1980, 1992; U.S. Soil Conservation Service, 1973; U.S. Power and Water Resources Service, 1980). Geology and groundwater studies in the South Dakota part of the map area include those by Hedges (1975), Simpson (1960), and Christensen (1974). J. E. Todd (1912) wrote an early work on Pleistocene drainage development in the basin that was followed by works by R. H. Williams (1984) and Voorhies and Goodwin (1989). Landforms have been analyzed for parts of the area by Flint (1955), Swinehart (1990), and Guthrie (1990). Considerable work has been done and continues to be done by several geologists, hydrogeologists, and other researchers on the geology in and around the site of the proposed low-level radioactive waste storage facility in Boyd County (for example, Pierce, 1989; Rahn and Davis, 1989). Modern soil surveys have been completed for all of the counties in the eastern part of the basin in Nebraska and in the study area in South Dakota (Indra, 1979; Manhke and others, 1978; Plantz and Zink, 1980; Ragon and others, 1983; Schulte, in press; Shurtliff and others, 1988, 1990; Voightlander and others, 1992; and Zink and Schultz, 1985). Geologic maps of the study area in South Dakota have been prepared by Baker and others (1952), Collins and French (1958), Schoon and Sevon (1958), Stevenson and Carlson (1950, 1951), and Stevenson and others (1958, 1959). The area to the east of the study area in Nebraska was mapped by Burchett and others (1988). The authors of this report currently are preparing a geologic map of the O'Neill 1° x 2° area at a scale of 1:250,000 in cooperation with the U.S. Geological Survey.

Pre-Cretaceous Geology

What we know about the pre-Cretaceous geology of the Nebraska part of the eastern Niobrara Basin and areas to the south adjacent to the basin comes from logs and samples from about 50 oil and gas tests and from geophysical surveys. Precambrian rocks include mostly metamorphic rocks and some granite. An extension of the Sioux Quartzite occurs beneath the easternmost part of the basin (Carlson, 1993). Cambrian and Devonian rocks have been found only in the southeasternmost part of the area included in figure 1. Ordovician and Mississippian rocks occur from the southeastern part of the mapped area in Nebraska northwestward into South Dakota (Carlson, 1993). Pennsylvanian-age rocks have been found beneath the western part of the basin, but no Permian, Triassic, or Jurassic rocks are known (Carlson, 1993).

Nebraska	South Dakota
Cenozoic Erathem	Cenozoic Erathem
Quaternary System	Quaternary System
*Holocene and Pleistocene Fluvial Terrace Deposits (Up to Five)	*Holocene and Pleistocene Fluvial Terrace Deposits
Holocene and Pleistocene?	Holocene and Pleistocene?
Eolian Sand	Eolian Sand
Pleistocene Peoria Loess (And Possibly Older Loesses)	Pleistocene Loess
*Pleistocene Unnamed Fluvial Units Filling Paleovalleys (Two or More)	*(Equal to Bon Homme Gravel and Tyndall Sand of Christensen, 1974, east of Missouri River)
Tertiary System	Tertiary System
Pliocene Series	Pliocene Series
*Pettijohn Formation (Skinner in Skinner and Hibbard, 1972)	
*Duffy Formation (Skinner in Skinner and Hibbard, 1972)	
**Long Pine Formation (Skinner in Skinner and Hibbard, 1972)	*Herrick Gravels (Stevenson and Carlson, 1950)
**Keim Formation (Skinner in Skinner and Hibbard, 1972)	
Miocene Series	Miocene Series
Ogallala Group (Darton, 1899; Revised by Lugn, 1938; Further Revised and Expanded by Swinehart and Others, 1985)	Ogallala Group
Ash Hollow Formation (Engelmann, 1876)	Ash Hollow Formation
*Unnamed Hemphillian Member (Skinner and Johnson, 1984)	
**Merritt Dam Member (Skinner and Johnson, 1984)	
**Caprock Member (Skinner, Skinner, and Gooris, 1968)	*Caprock Member
Valentine Formation (Barbour and Cook, 1917)	Valentine Formation
**Burge Member (Skinner, Skinner, and Gooris, 1968)	*Burge Member
**Devil's Gulch Member (Skinner, Skinner, and Gooris, 1968)	Devil's Gulch Member
**Crookston Bridge Member (Skinner, Skinner, and Gooris, 1968)	
**Cornell Dam Member (Skinner and Johnson, 1984)	
	**Fort Randall Formation (Skinner and Taylor, 1967)
Lower Miocene-Upper Oligocene Series	Lower Miocene-Upper Oligocene Series
Arikaree Group (Darton, 1899; Revised by Lugn, 1938)	
	**Turtle Butte Formation (Skinner, Skinner, and Gooris, 1968)
*Rosebud Formation (Matthew and Gidley, 1904; Detailed by Skinner, Skinner, and Gooris, 1968)	Rosebud Formation
White River Group (Meek and Hayden, 1858; Refined by Lugn, 1938)	White River Group
Chadron Formation? (Darton, 1899)	Chadron Formation?
Mesozoic Erathem	Mesozoic Erathem
Cretaceous System	Cretaceous System
Upper Cretaceous Series	Upper Cretaceous Series
Pierre Shale (Meek and Hayden, 1862)	Pierre Shale
Niobrara Formation (Meek and Hayden, 1862)	Niobrara Formation

**=Contains fossil mammal remains of national/international significance
*=Contains fossil mammal remains of local/regional significance

Table 1. Cenozoic and Late Mesozoic Deposits Along the Eastern Part of the Niobrara Drainage Basin in Nebraska and in Adjacent Parts of South Dakota West of the Missouri River

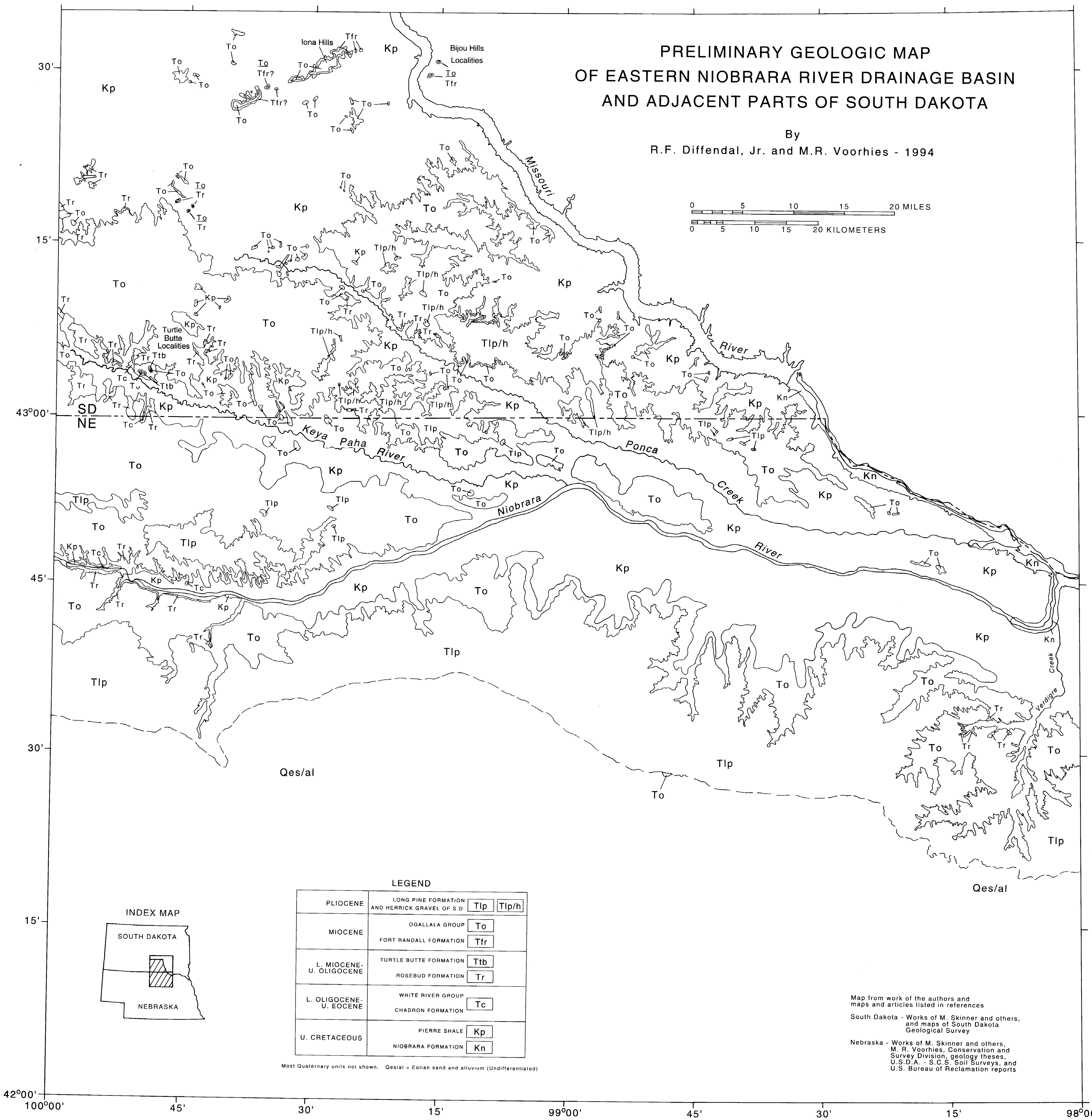

Fig. 1. Preliminary Geologic Map of Eastern Niobrara River Drainage Basin and Adjacent Parts of South Dakota

Mesozoic Erathem-Cretaceous System-Lower Cretaceous Series

The Dakota Group of Early Cretaceous age is a source of groundwater in parts of the basin and is known to occur beneath the map area, as do other Cretaceous formations older than the Niobrara.

Mesozoic Erathem-Cretaceous System-Upper Cretaceous Series

The oldest Cretaceous formation exposed in the area is the Niobrara (fig. 1; tables 1 and 2). Limestones and chalks of the Niobrara crop out discontinuously along the sides of the Missouri Valley, the lowermost Niobrara Valley and lowermost Ponca Creek valley. The Niobrara underlies the entire study area. The formation was deposited on the floor of a shallow sea that extended from the position of the present Arctic Ocean south to the present Gulf of Mexico. Marine organisms abounded in the waters of this seaway, and their skeletal elements form the major part of the formation. Beds of bentonite (a claystone formed from altered volcanic ash) indicate that volcanoes were present in land areas to the west that bordered the seaway and that eruptions from these volcanoes affected the seaway. Most paleogeographic reconstructions show that our part of the seaway was much closer to the equator in Niobrara times than it is today, so we have inferred from this and the types of fossils present in the deposit that the waters of the seaway were warm. At the end of deposition of the Niobrara, the seaway shallowed for a time and an erosion surface (unconformity) formed (DeGraw, 1975). The amount of time between the end of deposition of the Niobrara and the start of deposition of the overlying Pierre Shale is not known for certain, but we have used information given to us by D. K. Watkins (1993, personal communication) to estimate the gap at about 6 million years (table 2).

Whatever the length of time represented by the Pierre/Niobrara unconformity, the seas deepened over the study area once again in Late Cretaceous time. This time the sea-floor conditions were different, and the sediments that were deposited were mostly dark muds with sulfate and other minerals. While clam and oyster fossils are common in the Niobrara (Pabian, 1970), they are largely absent from the Pierre. This indicates that the sea floor was inhospitable to bottom organisms most of the time. Organisms that floated and swam in the waters above the floor, however, are present as fossils in the Pierre, proving that at least the surface waters were habitable. Bentonites also occur in the Pierre, so volcanoes must have been present in distant areas at the time the Pierre accumulated. At the end of Pierre deposition in the area, the seas withdrew. A major gap occurs in the geologic record above the Pierre (table 2). Exactly what happened in the area between deposition of the Pierre and the Chadron Formation of Cenozoic age is not known.

Cenozoic Erathem-Tertiary System-Upper Eocene to Lower Oligocene

Weathered uppermost Pierre Shale occurs in places, indicating that soil-forming processes were going on in the area before deposition of any Cenozoic rocks. The unconformity at the top of the Pierre has considerable relief and has a dendritic drainage pattern resembling those forming in lands underlain directly by Pierre Shale today.

The oldest Cenozoic formation known in the study area is the Chadron Formation of the White River Group. So far as we know, the Chadron in Nebraska was first observed in the study area by V. H. Dreeszen and in South Dakota by M. F. Skinner. The Chadron is known to crop out in only three small areas in Keya Paha County in Nebraska and in the Turtle Butte area in South Dakota (fig. 1). From what we can tell from these limited exposures and from other reports, the Chadron filled valleys eroded into the Pierre. Clays in the Chadron are derived from alteration of volcanic ash and from minerals such as feldspars in the sediments. Western volcanism contributed consid-

*MYBP	FORMATION	SEDIMENT TYPES	KEY GENERA OR SPECIES	TYPICAL FOSSILS	ENVIRONMENT
0	Terrace Deposits, Eolian Sand, Loess	Sand and gravel caps strath terraces; sand, very pale brown; silt, sandy, very pale brown.	Bison Mammuthus	Large grazing mammals and rodents.	Glacial and interglacial climates alternate.
	Valley Fills	Sand and gravel from distant and local sources fill paleovalleys.			
5	Pettijohn-Keim Fms.	Sand and gravel. Sand, silt, and clay, red to brown; stratified. Sand and gravel, includes anorthosite from Rocky Mountains, cross-stratified. Sand and locally derived gravel filling channels; grades upward to clay-filled pink to gray sand and then to gray sandy clay.	Stegomastodon, Borophagus Gigantocamelus, Ondatra Equus (Dolichohippus), Geomys	Fossils common. Grazing horses, giant camels, short-jawed gomphotheres, and bone-crushing dogs are predominant larger mammals. Burrowing rodents (gophers, ground squirrels) show adaptation to steppe environment while muskrats, voles and shrews indicate a temperate-climate marsh environment.	Temperate grassland/parkland with riverine woodlands.
10	Ash Hollow Formation Ogallala Group	Sandstone, gray, calcareous, interbedded with less consolidated sand and volcanic ash lentils; overlain by thinner bedded calcareous sandstone; younger deep cuts filled with unconsolidated sand.	Megalonyx, Prosomys Pseudhipparion skinneri — Pseudhipparion gratum B. morrisi — Barbourofelis whitfordi Ustatochoerus major — U. skinneri	Fossils abundant, especially tortoises, grass seeds, and large grazing mammals (horses, rhinos, camels, ruminants). Browsers and aquatic vertebrates common only in stream channel deposits. Many species of browsers become extinct during this interval.	Forests persist only in river valleys; savannas occupy interfluves. Climate still warm but drier than before.
	Valentine Formation, Ogallala Group	Sand, pale olive, friable, cross-stratified; sandstone, pale olive, argillaceous; one volcanic ash, light gray; sand and gravel, cross-stratified.	Pseudhipparion retrusum Cranioceras skinneri — C. mefferdi Bouromeryx americanus M. furcatus — M. warreni U. profectus — U. medius	Fossils abundant. Aquatic species include fish, alligators, turtles. Fossil wood and grass seeds common. Diverse vertebrate microfauna including frogs, toads, salamanders, snakes, lizards, amphisbaenids, shrews, moles, hedgehogs, plesiosoricids, rodents, rabbits, and pikas. Larger mammals include abundant proboscideans (both long-jawed gomphotheres and true mastodons), tapirs, rhinos, horses, chalicotheres, peccaries, oreodonts, camels, ruminants, and carnivores. Among the hoofed mammals grazers individually outnumber browsers at most sites but browsers are more diverse (larger number of taxa).	Large permanent streams and well-watered floodplains supporting forests; Savanna woodlands on interfluves. Frost-free climate.
15	? Fort Randall Formation ?	Clay, sandy clay, and silty sand, light gray, pink, red, brown, pale olive; barite and calcareous concretion horizons present; strata massive.	Merycodus necatus U. shrammi		
20					
	Turtle Butte Formation, Arikaree Group	Siltstone, white to light gray, tuffaceous; siltstone, calcareous; clay, white; sand and silt, reddish brown; strata massive to thick bedded.	Enhydrocyon crassidens Archaeohippus equinanus Megoreodon hollandi Archaeotherium trippensis	Fossils uncommon. Small but diverse samples of fish, lizard, turtle, and mammal fossils known.	Channel and floodplain; warm climate.
25	Rosebud Formation, Arikaree Group	Siltstone and silty sandstone, pinkish gray to brown, minor olive colors; massive to stratified; tuffaceous; includes local channels filled with reworked siltstone and sandy siltstone gravels, with silts filling pore spaces between grains, pale pink and some light olive colors, massive to grossly cross-stratified.	Centetodon magna Desmatochoerus Leptauchenia Paleocastor	Fossils rare. A few oreodont, rodent and insectivore jaws.	Floodplain in seasonally arid environment?
30					
35	Chadron Formation?, White River Group	Sand, white; sandy clay, tan to olive; clay, sandy clay, and sand, purple, red, white, and tan; tuffaceous; deeply weathered.		No identifiable fossils known.	Warm, humid fluvial.
70					
75	Pierre Shale	Shale, black, gray, and brown, thinly laminated; chalk, shaley, light gray, laminated; bentonite, white to gray.		Nannofossils Foraminifera Bivalves Ammonoid Cephalopods Sharks, Bony Fish Marine Reptiles	Shallow marine.
80					
85	Niobrara Formation	Chalk, shaley, medium gray; limestone, gray, yellowish-orange, grayish-orange; bentonite, white; stratified.		Nannofossils Foraminifera Ostracods Bivalves Ammonoid Cephalopods Bony Fish, Sharks Marine Reptiles	Shallow marine.

*MYBP = Millions of Years Before Present

(hatched box) = No Rocks of This Age Known in Area

Table 2. Cenozoic and Late Mesozoic Geologic Time Spans, Formations, Sediment Types, Typical Fossils, and General Environments--Eastern Niobrara Basin and Adjacent Parts of South Dakota West of the Missouri River

erable sediment in the form of airfall ash to the Chadron (Swinehart and others, 1985).

Cenozoic Erathem-Tertiary System-Upper Oligocene to Lower Miocene

There is another unconformity separating the Chadron from the overlying Rosebud Formation (table 2). The Rosebud was deposited in paleovalleys eroded into both the Chadron and the Pierre. The Rosebud rock types are noted in table 2. The sand and silt in the Rosebud is dominantly composed of volcanic debris. Gravels in channel fills within the Rosebud are mostly reworked older pieces of Rosebud. This is also true of gravels at the base of the formation, but these may also include pieces of Chadron and Pierre rocks as well. A borrow pit on the east side of U.S. Highway 183 south of Springview about 2 mi (3 km) north of the Niobrara River has multiple cuts in the Rosebud Formation filled with crudely stratified siltstone gravels that may have been deposited by debris flows. An erosion surface separating two parts of the Rosebud is visible to the east of the south abutment of Norden Bridge along the Niobrara just west of the study area. These last two localities demonstrate that multiple cutting and filling of paleovalleys took place during formation of the Rosebud in and adjacent to parts of study area.

The Rosebud Formation crops out extensively along valley sides in the western part of the study area (fig. 1) and also has been found in isolated small areas in the Verdigre Creek drainage basin (fig. 1; and in Schulte, 1952, and Voorhies, 1973). Burchett (1986) called these exposures part of the White River Group, but we believe that they are younger and are the basal part of the Arikaree Group instead, following the opinions of M. F. Skinner on this point.

In South Dakota, a younger unit called the Turtle Butte Formation (fig. 1; tables 1 and 2) unconformably overlies the Rosebud (Skinner, Skinner, and Gooris, 1968). So far as we know, this unit occurs only at Turtle Butte. It has been included in the Arikaree Group with the Rosebud because of the stage of evolution of its fossils and its large volume of volcaniclastic sediments.

Cenozoic Erathem-Tertiary System-Miocene Series

A long period of erosion separates the Turtle Butte Formation and older units from the younger Miocene units assigned to the Ogallala Group. Skinner and Taylor (1967) described the Fort Randall Formation, which lies unconformably above the Pierre Shale in South Dakota at the Bijou Hills east of the Missouri River, and in the remnants west of the river called the Iona Hills, etc. (fig. 1; tables 1 and 2). While the rocks somewhat resemble the older Turtle Butte Formation, they contain much younger fossils. Skinner and Taylor thought that the formation was equivalent in age to the Lower Snake Creek beds of western Nebraska, but proboscidean and other fossils found subsequent to their report indicate a somewhat younger age for the formation. We have shown this in table 2. So far as we know, the Fort Randall Formation is restricted to the area in South Dakota shown on figure 1.

A brief hiatus separates the Fort Randall from the main parts of the Ogallala Group in South Dakota, but in Nebraska the lowermost parts of the Valentine Formation are contemporaneous with it. Skinner and co-workers (table 1) have subdivided the Ogallala's two formations, the Valentine and overlying Ash Hollow, into a number of members. These members do have lithologic differences that allow them to be traced laterally in outcrops. No one has successfully traced them in the subsurface, however. They also have not been widely recognized in South Dakota, but Skinner, Skinner, and Gooris (1968) reported some of them at Turtle Butte. Within the Valentine Formation, only the Devil's Gulch Member seems to be conformable everywhere. All the other members are complex valley fills that often look conformable locally, or even regionally, but are shown in Skinner and Johnson (1984) to be far more complex. The basal member of the Ash Hollow Formation, the Cap Rock, is also a regional calcium-carbonate-cemented marker bed, but fills paleovalleys in some places. The other two members of the Ash Hollow also fill paleovalleys eroded into older beds (Skinner and Johnson, 1984). Multiple cutting and filling of paleovalleys during deposition of the Ogallala Group has been recognized in western Nebraska (Swinehart and Diffendal, 1990), and this seems to be the case in places in north-central Nebraska as well, albeit usually on a much more subdued scale. The Ogallala Group in the study area has yielded truly remarkable accumulations of fossil vertebrates. Many of these species are noted in the papers of Skinner and his colleagues. The Ashfall Fossil Beds State Historical Park in northwestern Antelope County is one of the most spectacular of these sites found to date and has been described in detail by Voorhies (1985, 1990a).

Cenozoic Erathem-Tertiary System-Pliocene Series

Skinner and Hibbard (1972) recognized four formations (table 1) now placed in the Pliocene. The oldest of these, the Keim Formation, fills a narrow paleovalley north of Ainsworth, Nebraska. The much more widespread Long Pine Formation and its equivalent in South Dakota, the Herrick Gravels, crop out widely in the study area and occur in the subsurface. Skinner and Hibbard (1972) thought that the Long Pine was an outwash deposit from the Nebraskan Glaciation, but works by Stanley (1971), Stanley and Wayne (1972), Swinehart and others (1985), and Swinehart and Diffendal (1990) have demonstrated conclusively that the fluvial system that deposited the Long Pine came from the Southern Rocky Mountains in southern Wyoming and north-central Colorado.

The Long Pine is a braidplain deposit that fills a very wide paleovalley. This deposit continues across the state line into South Dakota, where it has been mapped as the Herrick Gravels. Fossils from the South Dakota deposits are from the Blancan Land Mammal Age (Pinsof, 1985), as are those from Nebraska. Some of the northwesternmost parts of the Herrick may have been deposited by rivers from the Black hills or other areas. Pebble studies by Diffendal and colleagues now underway may answer this question. Locally overlying the Long Pine are the Duffy and Pettijohn formations. They are known to occur only in the vicinity of Long Pine and the upper Elkhorn River valley in Nebraska. All four units have been lumped together on figure 1 for reasons of scale.

Cenozoic Erathem-Quaternary System-Pleistocene and Holocene Series

The Quaternary geologic history of the study area is complex. Several geologic units are present, and many of these are unconformable. Noteworthy are the valley fills along Ponca Creek, the eolian sands of the Nebraska Sand Hills, several strath terraces in various drainages, and Holocene alluvium. These are noted on tables 1 and 2, but except for the main part of the Sand Hills, are not shown on figure 1. We are investigating these as part of our mapping project and plan to show at least some of them on the 1:250,000 geologic map.

Possible Evidence of Structures

We have not observed faulting in the area, but several features may indicate structural effects. The discontinuous exposures of the Rosebud and Chadron along the Niobrara River near the western margin of the study area may indicate structural control. The distribution of the Paleozoic rocks shown by Carlson (1993) may also be structurally controlled. The northeastward trend of the northernmost outcrop belts of the Fort Randall, Ogallala, and Long Pine/Herrick units on figure 1 may also indicate structural control, as may lineaments on Landsat images. Displacements along fractures in the Pierre east of Spenser Dam may indicate faulting or landslides.

Geologic Hazards in the Area

Landslides have been and continue to be observed in the Nebraska part of the study area by D. A. Eversoll and other workers at the Conservation and Survey Division of the University of Nebraska-Lincoln. They occur commonly in parts of the Pierre Shale, but also occur in other units. We have seen them develop in the Pierre and the Fort Randall in South Dakota as well. Flooding is also a problem in some areas. Earthquakes have occurred in the study area (U.S. Water and Power Resources Service, 1980).

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